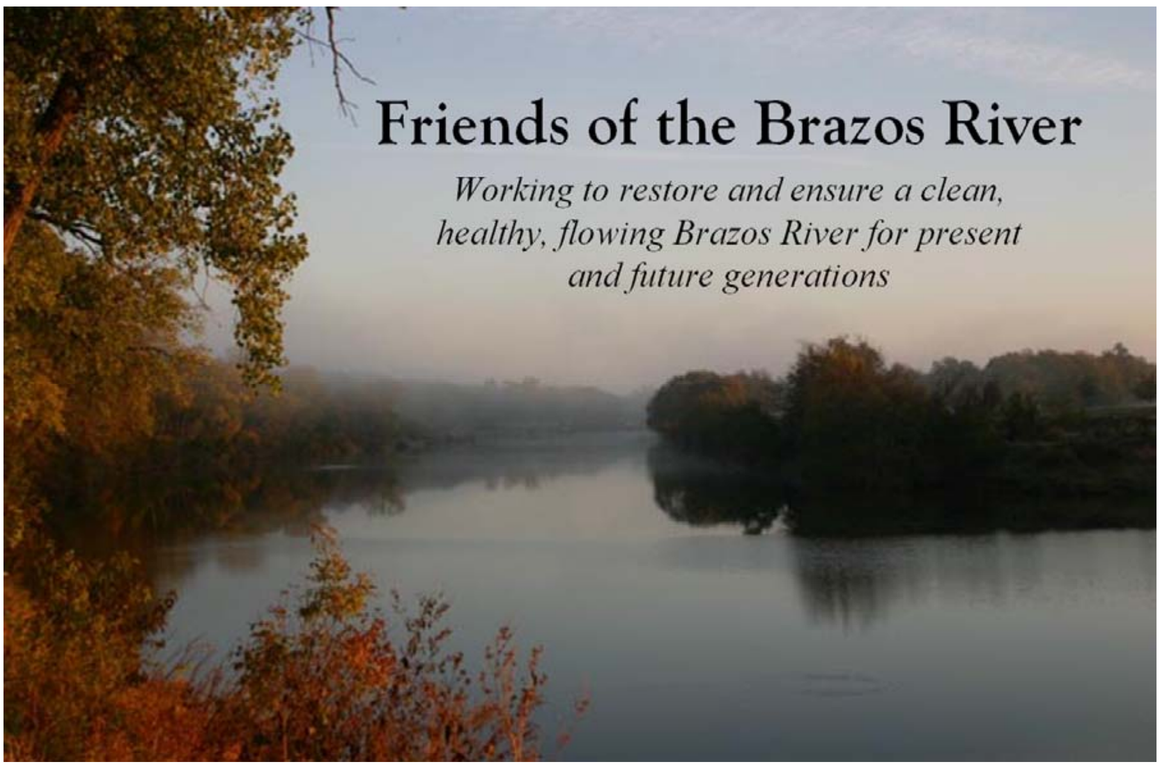
Instream Flow Needs for the Brazos River near Glen Rose, Texas

Instream Flow Analysis
Water Availability and Reservoir Operations
Alternatives and Implementation Analysis



Prepared for
Friends of the Brazos River

Prepared by
Trungale Engineering & Science

July 2, 2007

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Executive Summary

The protection of instream flows for Texas Rivers has been recognized by the Texas Legislature and state agencies as one of the most important natural resource priorities in the state. Instream flow regimes require flows of specific magnitudes, durations, frequencies and timing to provide aquatic habitat, transport sediments and maintain water quality to support diverse plant and wildlife assemblages.

This report provides a flow recommendation for the Brazos River between lakes Granbury and Whitney. The recommendation is based on the natural flow regime and seeks to mimic ecologically significant components of the natural hydrograph. The analysis was undertaken in response to concerns associated with potential changes in the management of the river as envisioned in the Brazos River Authority's (BRA) recent application for new diversions of up to one million acre feet of water from the Brazos River.

In addition to developing the recommendation, a preliminary water availability analysis was conducted in order to evaluate the potential for meeting basic ecological flow needs in conjunction with growing out of stream demands for water. To address this issue the BRA permit application and the supporting water availability model (WAM) which accompanies it, were carefully reviewed. From this review it can be shown that for the immediate future the granting of this permit would result in a substantial surplus in water supply and it appears that this surplus would, at least until 2020, be sufficient to provide the quantity of water needed to protect the ecosystem.

Based on this analysis we find that the BRA's systems operation permit has the potential to significantly and negatively impact the ecological health of the Brazos River. However it appears that the granting of BRA's permit would provide more water than is needed to satisfy out of stream demands. This surplus water could be used to protect and restore the ecological health of

the river. The instream flow recommendations put forward in this report are very preliminary though they provide a reasonable estimate of recommendations that might be developed through a more formal process. The BRA should immediately undertake such a process to develop a flow regime recommendation and identify critical information gaps. Such a recommendation should replace the minimum flows in the BRA systems operations permit. Research priorities identified through this process should be incorporated into the Texas Instream Flow Program.

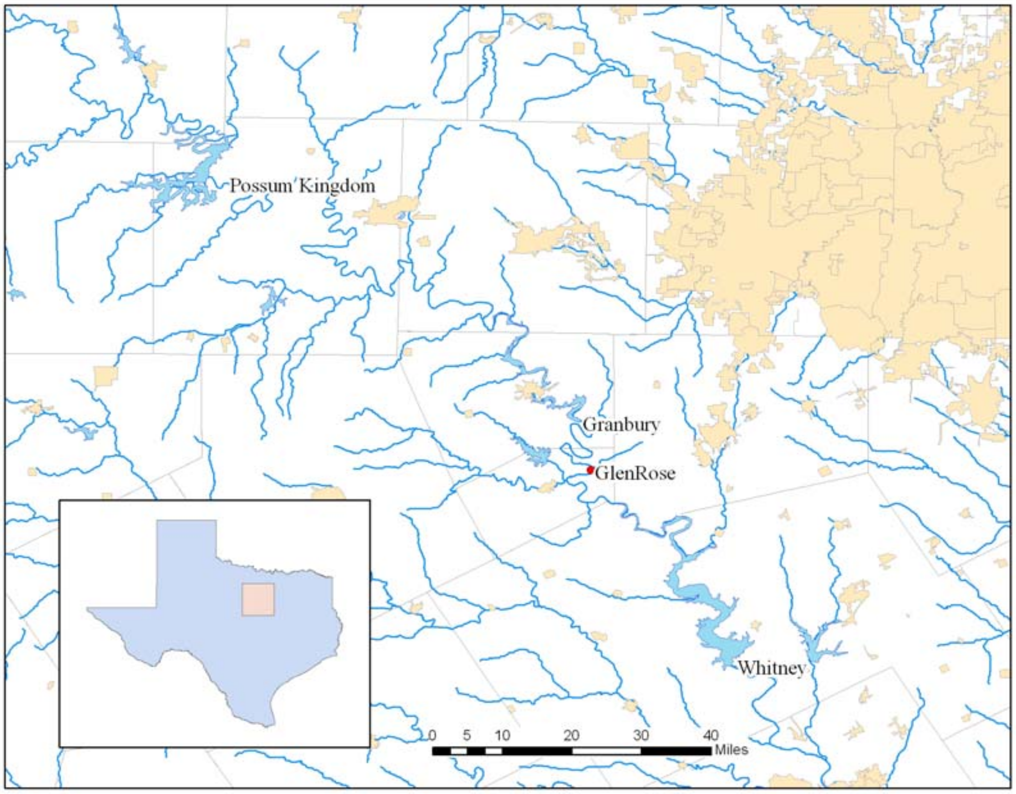
Introduction

The objectives of this study are to determine the basic environmental and recreational flow requirements of the Brazos River between Lake Granbury and Lake Whitney, how the current operations regulate flows in this stretch and, how the proposed Brazos River Authority (BRA) System Operation Permit could affect the ecological health of the river ecosystem. This report examines the pre-development, current and proposed flow regimes. The pre-development hydrology of the river (1923 - 1940) is examined to develop recommendations for biologically significant components of the flow regime that should be maintained or restored to protect the Brazos River ecosystem. Next the current operating regime is examined by reviewing how flows are managed in the current operating system by reviewing several sets of seasonal flow records from 1970 - 2003. The final sections evaluates the proposed BRA's Systems Operation permit application and considers various alternatives to manage this flow in a manner beneficial to the instream needs of the Brazos River.

Study Area

This report focuses on the segment of the Brazos River which flows from Lake Granbury to Lake Whitney.

Figure 1 Study Segment with proposed Glen Rose Diversion Location



Flows in the segment have been significantly altered from their natural conditions. Although many factors may have contributed to these alterations including groundwater pumping and its impacts on springflow, changes in land use, direct streamflow diversions and wastewater returns, and the construction of in-channel reservoirs, this study will be concerned with the management of the reservoir system at Lakes Possum Kingdom and Granbury and the major Brazos River diversions between Lake Granbury and Whitney.

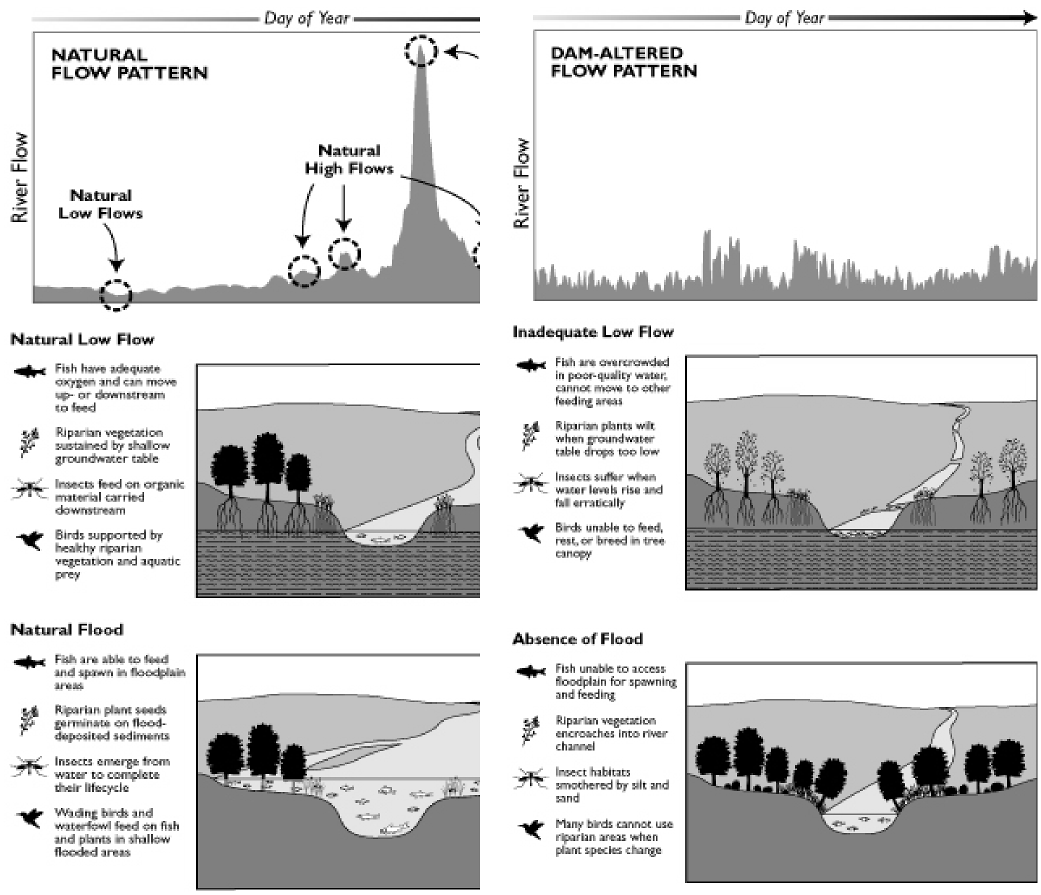
The Science of Instream Flows

The science of instream flows provides a number of approaches to developing flow recommendations for the protection of a sound ecological environment. The most simple, quick and inexpensive approach is assume some percentage of normal flows would be sufficient to protect the aquatic ecosystem. In Texas the default method employed is referred to as the Lyon's method. This approach was developed in the 1970s and 80s and produces a minimum flow that is calculated as a percentage of historical median flows. The Lyon's targets were developed based on another method called the Tenant method, developed in the Western United States. The Tenant method is a wetted perimeter, visual inspection approach. In developing this method, data are collected at dozens of streams, stream health is evaluated, and relationships are developed between a percentage of the average annual flow and river health; for instance 40% of the mean average flow is a minimum flow and 60% is a healthy flow. In 1978, TPWD biologists visited a single site on the Guadalupe River and determined that 40% of the monthly median flow in the winter and 60% of the monthly median flow in the summer provides a good wetted perimeter. This rule of thumb has become enshrined in TCEQ guidance and has become the default starting point when deciding on the instream flow needs of any stream in Texas. There is value in this method in that it provides some level of instream flow protection and this protection has some relationship to the hydrology of the stream, however this approach was never intended for the purpose for which it is used in this application and is now far from the state of the art of instream flow science. Over the last 20-30 years the myth of a minimum flow has been rather thoroughly discredited as aquatic ecologists have come to recognize that a varied flow regime that mimics natural historical patterns and that maintains adequate sediment loadings is the key to sustaining fish and wildlife resources. The environmental analysis on the BRA systems operations permit is based on the rather simplistic Lyon's approach.

A far more comprehensive and scientifically defensible approach to setting instream flow targets is a comprehensive instream flow study. In 2001, the 77th Texas Legislature instructed the three primary water agencies in Texas, the Texas Water Development Board (TWDB), the Texas Parks and Wildlife Department (TPWD) and the Texas Commission on Environmental Quality (TCEQ) to develop a program to conduct these studies on Texas Rivers. This program is currently underway but the completion of these studies can cost hundreds of thousands of dollars and many years to complete. There are currently two such studies, of which the BRA is an active participant, in their early stage in the middle and lower Brazos basin. Unfortunately the geographic scope of these studies are defined based on water supply plans that have been largely superseded by the current BRA application and as a result the studies will not, if they proceed with there current design, be capable of addressing the instream needs of the area of the river being effected by this permit.

A middle path between these two extremes to developing instream flow recommendations is to develop recommendations based on the natural flow paradigm. There is broad consensus within the scientific community that healthy river systems require a range of flow conditions, i.e. a flow regime, rather than a single minimum flow target. These flow regimes are critical for specific ecosystem functions including the maintenance of habitat, water quality, channel and riparian structure, and flood plain connectivity. (Figure 2)

Figure 2 Ecosystem functions supported by natural flows



Graphic from "Rivers for Life: Managing Water for People and Nature" Postel, S. and B. Richter (Island Press 2003)

In this study pre-development flows are used to identify ecologically meaningful hydrologic components of the natural flow regime that should be preserved in order to maintain a healthy ecological community. This flow regime includes flows of certain magnitude, frequency, duration, timing and flow variability.

Ecosystem flow components are described in the Texas Instream Flow Program Technical Guidance document. While the program outlined in that document proposes to develop these flow recommendations with site-specific studies, the components are largely based on the methods developed as part of the Corps of Engineers-Nature Conservancy Sustainable Rivers Program. The first step in the Sustainable Rivers Program is to conduct an extensive literature review of hydrologic, biological, geomorphic, water quality and connectivity issues. Once all of the readily available data are assembled, a multidisciplinary team of specialists in hydrology, fluvial geomorphology, water quality and aquatic and terrestrial ecology review this information and an over the course of two to three days make preliminary flow recommendations and develop a list of research priorities. These recommendations are then tested within an adaptive management context in which the response of the ecosystem to the recommended flows is monitored and the recommendations refined as more is learned about the system. Although such a group has not yet been convened for the Brazos basin, this approach has been applied throughout the United States and in Texas in the Cypress Basin above Caddo Lake. The general approaches taken and lessons learned from these studies are used in this report to make specific base, high pulse and subsistence flow recommendations for the Brazos.

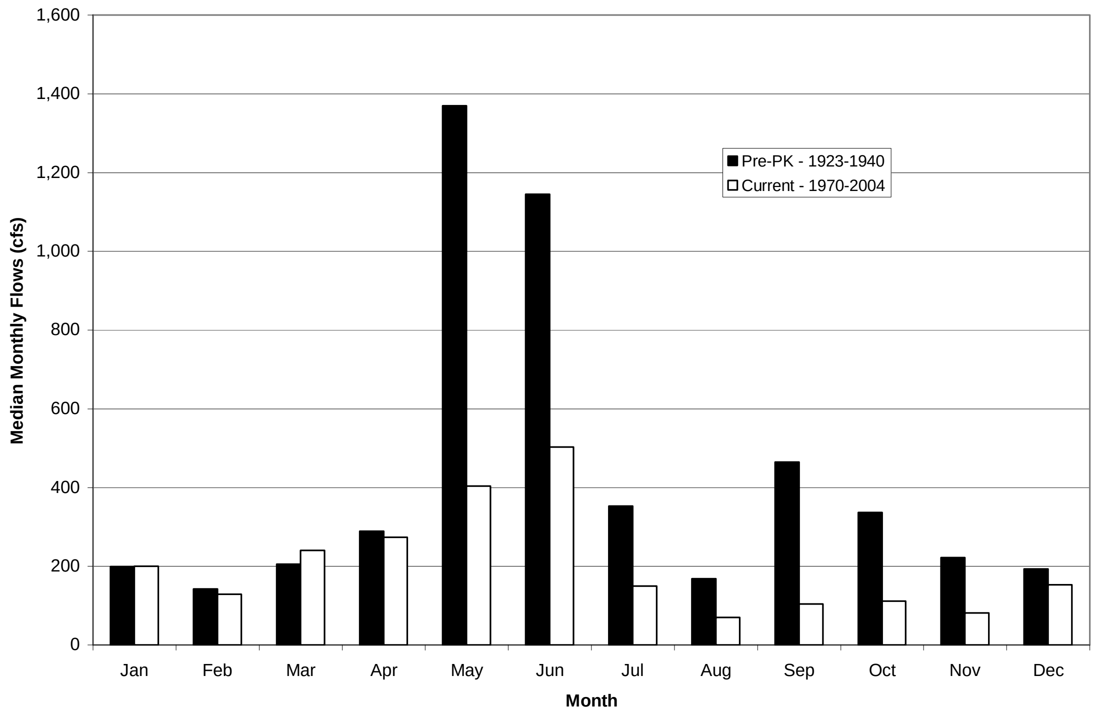
Natural Flow Regime for the Brazos River

In examining the natural historical flow record, one indicator considered to be biologically important is the seasonal pattern of natural flows, e.g., when do higher flows tend to occur, when do the lowest flows occur? The magnitudes of these flows are important in providing habitat for aquatic organisms and for providing water for plants and terrestrial animals. They also influence water temperatures, oxygen levels, and photosynthesis in the water column. The life cycles of aquatic and terrestrial species which make use of the river are linked to the timing of these flows.

Flows in the Brazos River at Glen Rose before the construction of Possum Kingdom Reservoir exhibited a fairly typical pattern of late spring peaks with smaller peaks in the fall (Figure 3). The annual median daily flow was 313 cfs while the spring high flows were around 1200 cfs and the fall high flow around 350 cfs.

Figure 3 Monthly Median Flows at Glen Rose

Pre and Post Possum Kingdom Reservoir (PK)



Clearly there has been a dramatic reduction in the magnitude in the spring through fall flows between the pre- and post- reservoir construction periods, while winter (Dec.-Feb.) flows apparently have been maintained. Although the magnitude of the spring peaks are reduced, the timing of these peaks in the seasonal flow pattern is still evident Fall peaks, however, have been eliminated. Analysis of the changes to the natural flow conditions raise two important questions that might be addressed by future studies are: 1) whether the peaks have been so diminished that they no longer provide the spawning cues to organisms which may time their reproduction to seasonal flow regimes: and 2) if the natural maintenance related to flushing and scouring of the channel is no longer provided.

In addition to seasonal flow conditions, it is also important to examine extreme conditions that are important factors in balancing competitive and stress tolerant organisms, providing for geomorphic alterations to habitats (structure of riffle-pool-run sequences) and providing for connectivity to the flood plain. One of the more common effects of reservoir development is the attenuation of extreme events of both high and low flows. Analysis of the hydrologic record for the Brazos River at Glen Rose reflects this change, indicating a general increase in low flows and a decrease in high flows (Table 1).

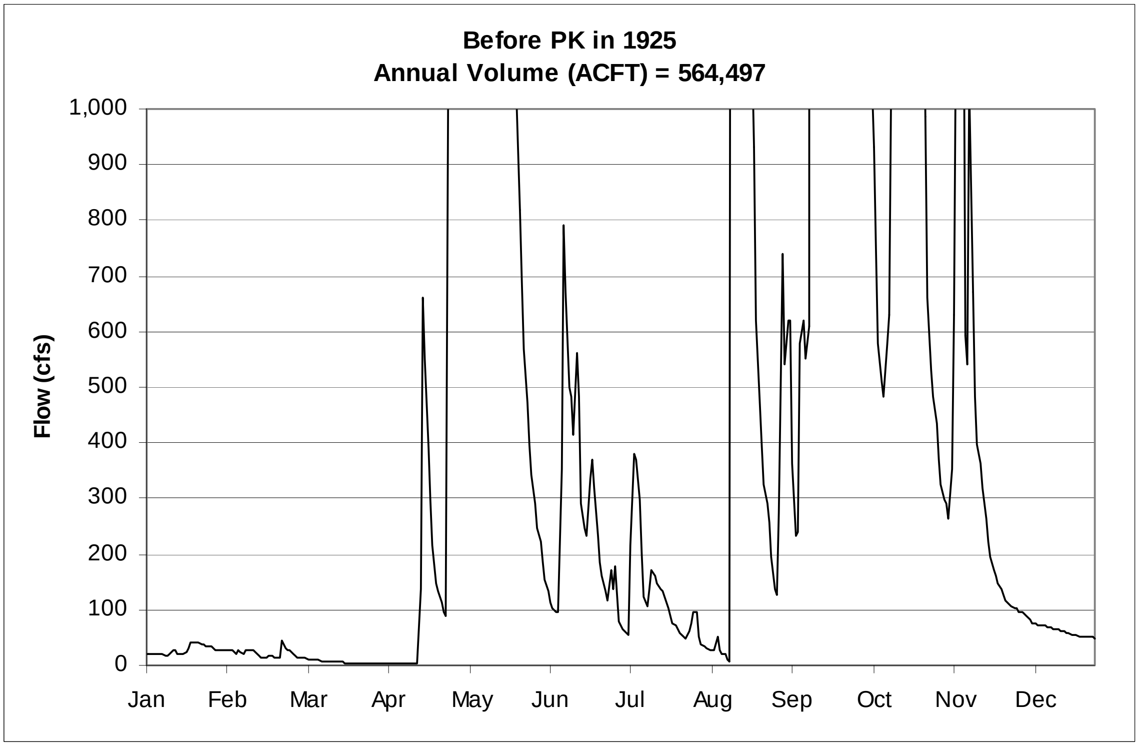
Table 1 Extreme Flow Events

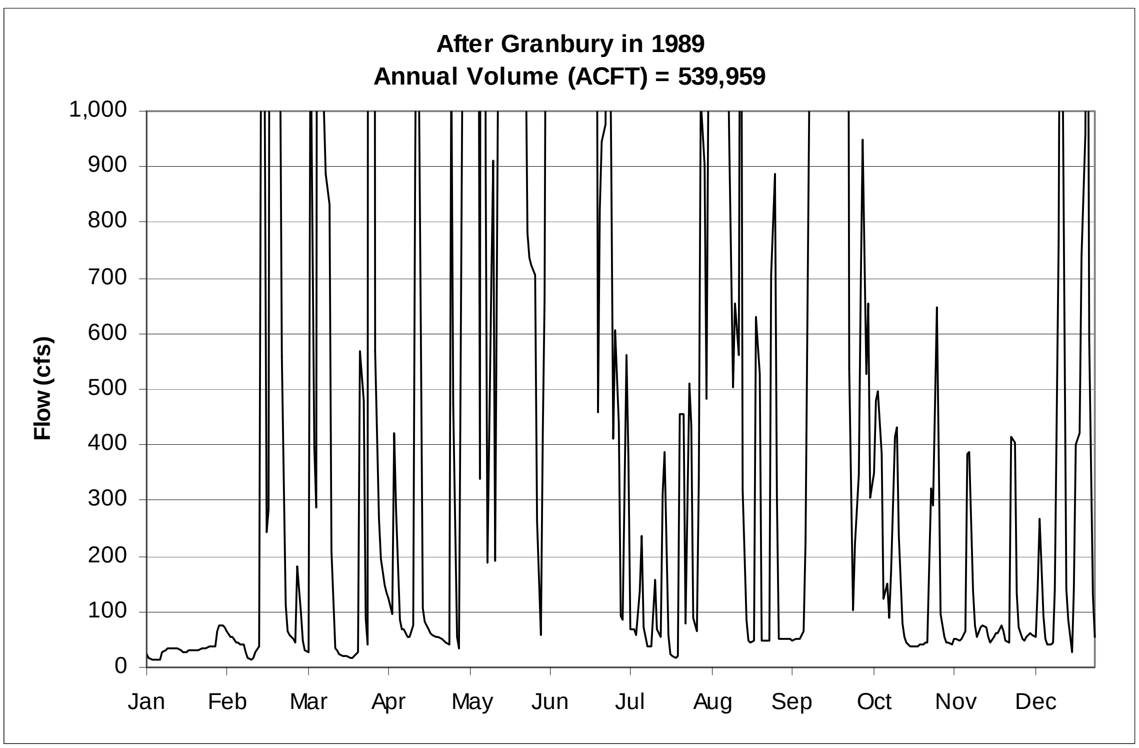
	Medians (cfs)	
	Pre	Post
1-day minimum	1.00	8.05
3-day minimum	0.87	9.48
7-day minimum	1.09	14.35
30-day minimum	9.37	29.63
90-day minimum	93.36	85.54
1-day maximum	34,500	15,650
3-day maximum	25,800	12,620
7-day maximum	16,820	8,148
30-day maximum	6,703	3,775
90-day maximum	3,943	2,149

Although it would be premature to draw definitive conclusions, the changes seen in flows during extreme events may decrease the abundance of drought tolerant native species and increase the abundance of exploitative invasive species due to the removal of the harsher low flow conditions. Reductions in high flows may decrease habitat structure through reductions in sediment transport capacity and nutrient replenishment provided by overbanking flows.

The rate of change in flow, or variability, is the last issue that will be addressed in this discussion of the river ecosystem components. This component refers to how much, how quickly and how often the river flow rises and falls. This is generally an important issue related to hydropower peaking operations in which the river edges are constantly wetting and drying potentially resulting in increased bank erosion and desiccation of low mobility stream edge organisms. The historical data indicate that the river now rises much less rapidly than in the pre-development period, presumably due to flood control provided by upstream reservoirs, while the rate of fall remains about the same. There is a large increase in the number of days in which the direction of flow rate reverses (flow increases one day and decreases the next). This flashiness is visually apparent in Figure 4 which displays flow less than 1,000 cfs for pre- and post- development hydrographs for years which have similar total annual flows. This may or may not significantly impact stream edge habitat.

Figure 4 Pre- and post- development hydrographs for years which have similar total annual flows





The analysis of seasonal flow patterns, peak extremes, and changes in flow rates are all important components in determining the flow needs of a healthy river ecosystem. A more complete analysis and subsequent field studies would likely shed light on the processes that these flow characteristics drive and thus reduce the uncertainty of subsequent flow recommendations; however the basic flow regime needs may be reasonably well predicted by analysis of flow data. It should be noted that using the naturalized flows to develop flow recommendations is not synonymous with recommending that the river be managed to reproduce natural conditions. Rather, understanding the functions of the natural regime can guide management decisions towards alternatives which minimize the impact on the aquatic ecology by water development projects.

Although not an ecological riverine component, recreational use of the river is an important societal and economic use of instream flows that should be considered in the development of flow recommendations. Previous studies conducted by TPWD, the Texas River Protection Association and Texas Christian University suggest flows between 200-1200 cfs are necessary for recreational uses such as canoeing.

Based on the analysis above the following goals can be proposed:

1. Restore summer and fall normal flow conditions
2. Provide occasional extreme low and high flow events
3. Decrease flashiness of the hydrograph so that the river edge is not in a constant state of wetting and drying.
4. Avoid very low flow conditions on the weekends to provide adequate recreational flows.

Current Operations

This section describes the operations of reservoirs on the Brazos River which determine the current flow regime near Glen Rose. This review is needed to understand the physical constraints within which a recommended flow regime needs to be tailored. Flows in the segment of the

Brazos River between Lake Granbury and Lake Whitney are controlled largely by releases from Possum Kingdom, attenuated as it passes through Lake Granbury and at times decreased by diversions.

Possum Kingdom is a large multi-purpose reservoir located in Palo Pinto, Stephens, Jack, and Young counties about 125 river miles upstream of Granbury. Morris Sheppard Dam, which forms Possum Kingdom, impounds 1,500,000 acre-feet of water annually for municipal, industrial, mining, irrigation, flood-control, recreational, and power-generation uses. Releases from Possum Kingdom are primarily for hydropower peaking. Typically as Brazos Electric makes calls for water releases, approximately 3,000 cfs are released, usually nightly, for several hours. This water attenuates as it travels downstream from Graford, located just below Possum Kingdom, and reaches Dennis, located just above Lake Granbury, about 2-3 days later (Figure 5). Figure 6 shows the peaks lagged, i.e. shifted to reflect travel time, to demonstrate attenuation.

Figure 5 Brazos River Flow Hydrograph

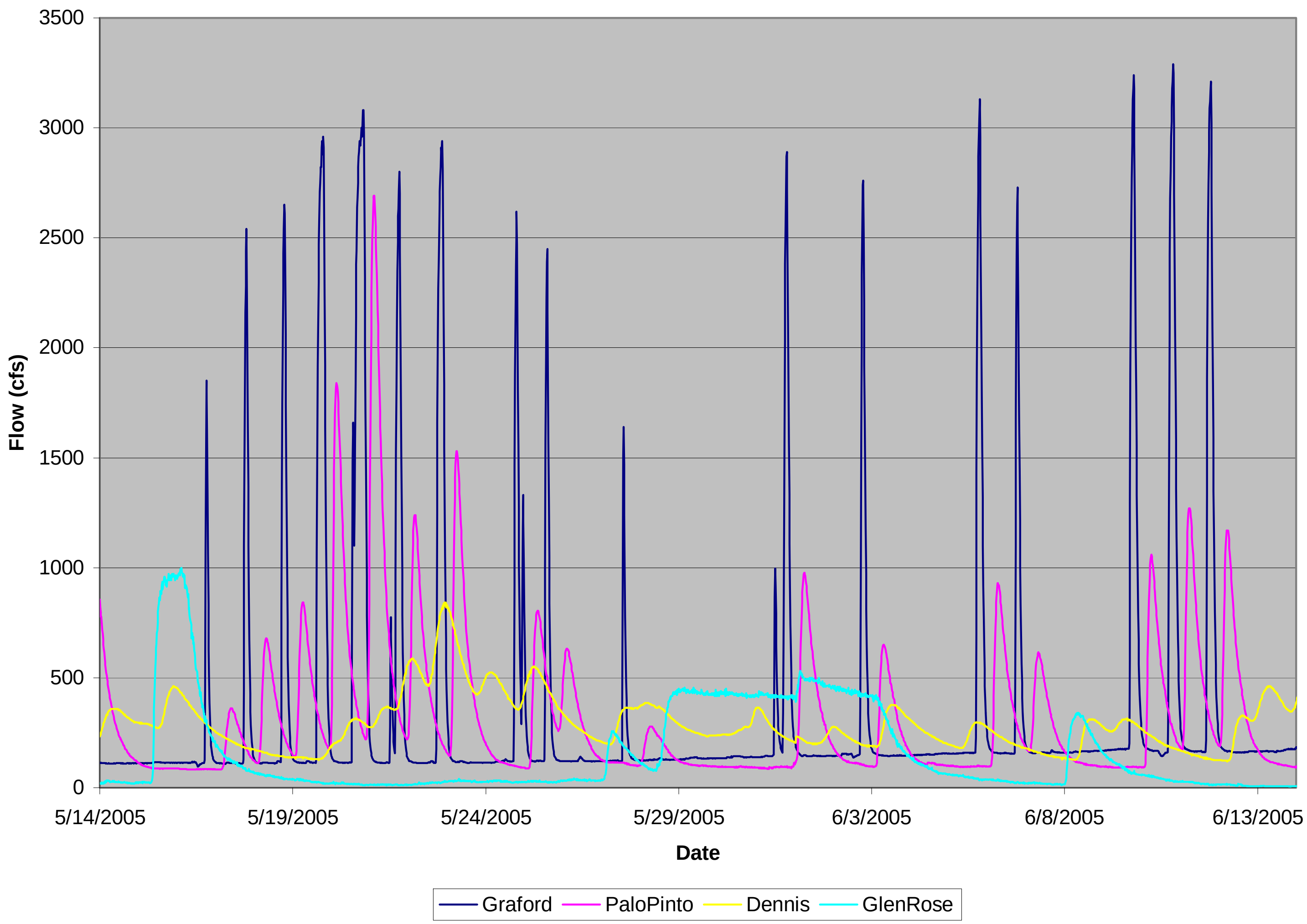
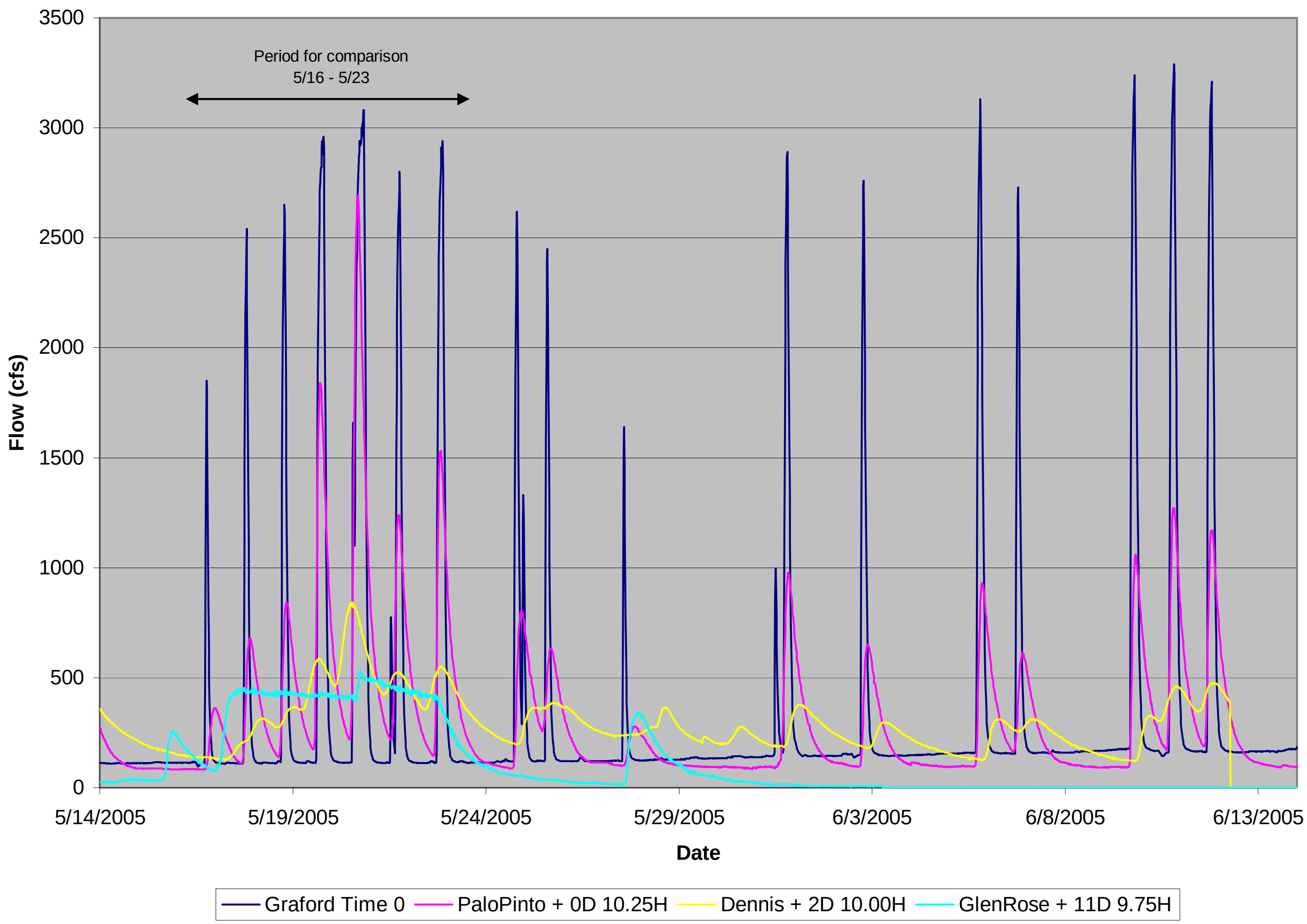


Figure 6 Brazos River Flow Hydrograph Lagged for Travel Time

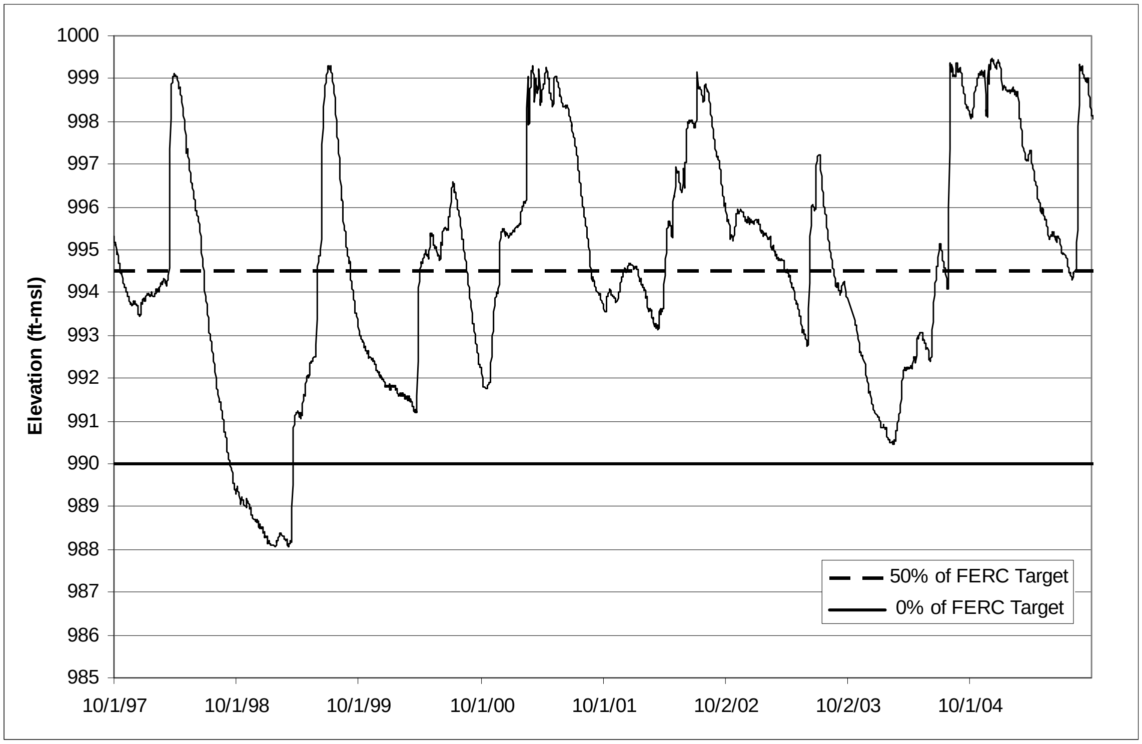


When releases are not being made for hydropower peaking, releases from Possum Kingdom are dictated by its Federal Energy Regulatory Commission (FERC) license. These minimum flow releases required by the license were negotiated between the BRA and state and federal resource management agencies. State and federal resource agencies argued for high flows to maintain aquatic habitat requirements for downstream species while the BRA and a coalition of lakeside property owners argued for lower release requirements in order to maintain reservoir levels for water supply and recreation. In the end a compromise was reached which included the following minimum flow release requirements.

- March through June – 100 cfs
- July through September – 75 cfs
- October through February – 50 cfs

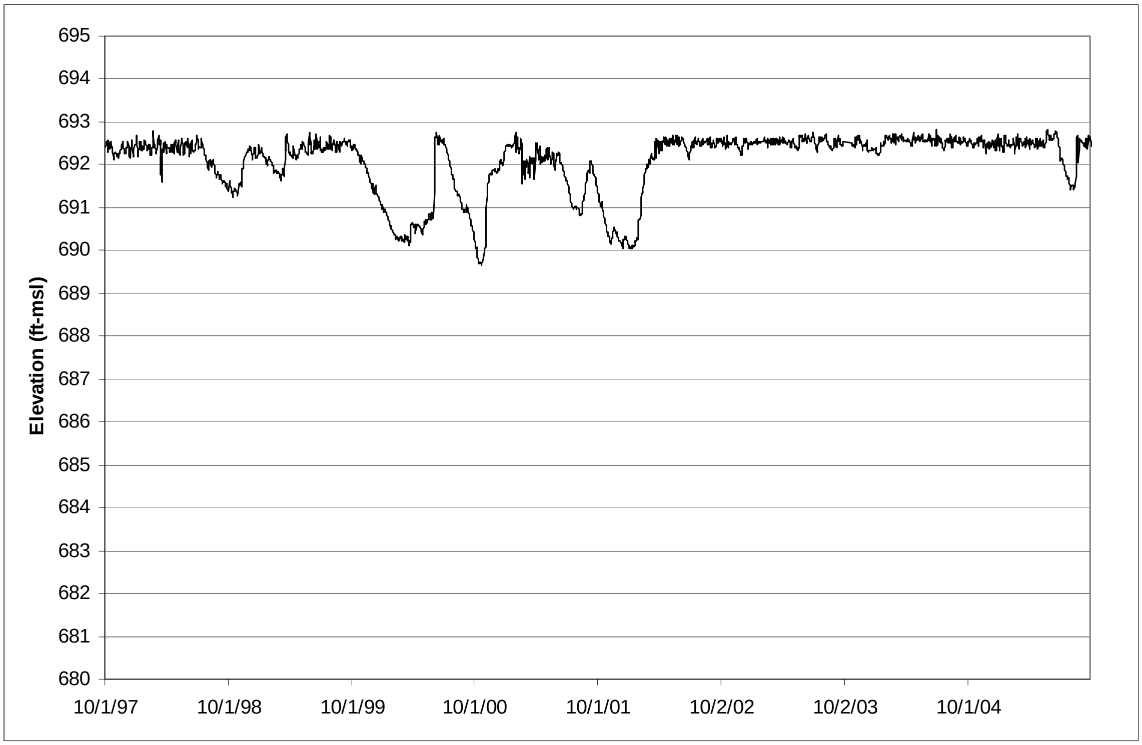
However the compromise included drought triggers which called for relaxation of the required release to half their original amount whenever the lake level at Possum Kingdom falls below 997 feet-msl and no releases are required when Possum Kingdom is less than 995 feet-msl. The result of these reservoir storage triggers are that, for the period from 1997-2004, about 5% of the time there were no required releases from Possum Kingdom and about 45% of the time the releases were half the amount originally deemed necessary by the natural resource agencies (Figure 7).

Figure 7 Possum Kingdom Lake elevation from 1997-2004



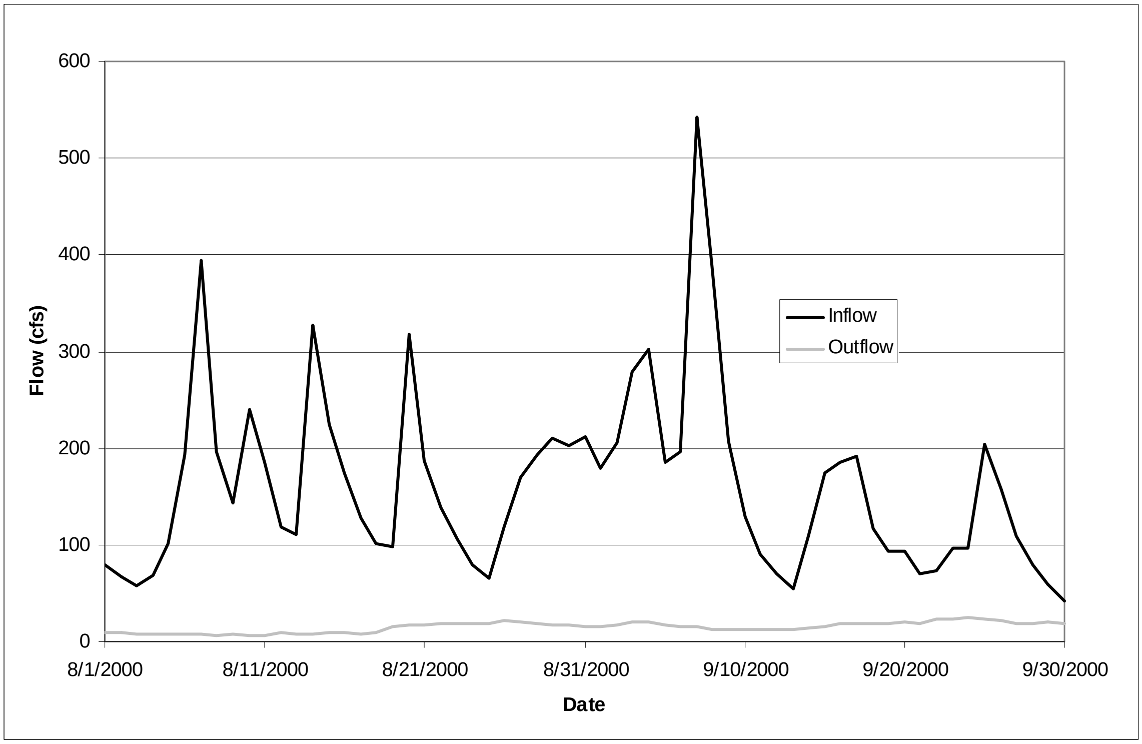
During normal conditions Lake Granbury is maintained at a nearly constant elevation. (Figure 8) Lake Granbury normally releases about 32 cfs. As hydropower peaks from Possum Kingdom are routed through the lake, the elevation rises about ½ of a foot (to an elevation of about 692.7 feet-msl) over a period of several days.

Figure 8 Lake Granbury elevation from 1997-2004



When Granbury is routing hydropower, releases are increased to approximately 500 cfs. These releases arrive at Glen Rose 1-2 days later. Once Lake Granbury returns to about 692.2 ft, releases are reduced back to approximately 32 cfs (Figure 5). When storage in Granbury is down, flows out of this reservoir are greatly reduced. During 2000, inflows to Lake Granbury at Dennis fluctuated around 150 cfs, while releases dropped to around 15 cfs (Figure 9)

Figure 9 Lake Granbury Inflow and Outflow during low flow period.



In summary, an examination of the current operating conditions indicates the following:

1. Flows in the stretch of the Brazos River between Possum Kingdom and Lake Whitney are dictated primarily by hydropower operations at Possum Kingdom.

2. During dry periods very little water is released from Lake Granbury.

3. These factors result in flows between Lake Granbury and Glen Rose constantly alternating between 30 and 500 cfs, with significant periods of flows of less that 20 cfs.

Flow Regime Recommendation

As stated above, the Lyon's analysis, while perhaps a useful place to start, is inadequate to assess the impacts of this project on the biological resources of the river system. What is needed is a comprehensive evaluation of the instream flow needs and a proactive commitment to satisfy these needs. In the interim the Lyon's approach should be replaced by a flow regime prescription based on the natural flow paradigm. Based on a review of the current scientific literature and experience with instream flow studies preformed in Texas, a set of preliminary flow recommendations have been developed for base, high pulse and subsistence flow as described below.

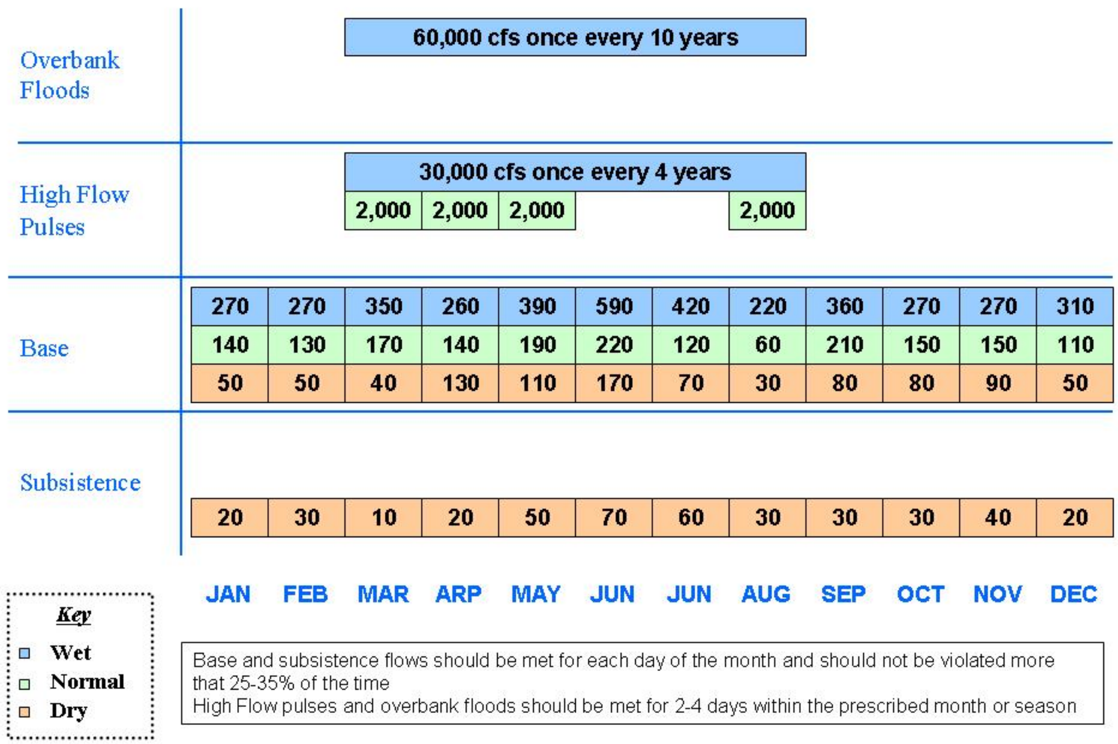
Base flow conditions are the flows experienced by the river during normal times i.e. when not flooding or experiencing severe drought. The flow targets are largely defined by requirements for aquatic habitats (e.g. runs, riffles, pools). Base flows are reasonably synonymous with the flows that are developed via the Lyons approach. The base flow targets developed in this study improve on the Lyons approach in two ways. First by applying a base flow separation analysis to the daily data series and second by providing for interannual variation by developing base flow targets for wet, normal and dry periods.

Overbank and high flow pulses are necessary to maintain physical habitat through transport and redistribution of sediments and to provide for longitudinal connectivity between the river and the flood plain. High flow pulses are events which normally occur several times every year for several days while overbank flows are less frequent events which may only occur every several years. Most commonly sited references related to bankfull flows refer to effective discharge which is the flow that, on average, moves the majority of the sediment in a channel and is largely responsible to channel maintenance.

The primary objective of subsistence flows is to maintain water quality criteria typically defined by water chemistry parameters such as temperature and dissolved oxygen. The secondary objective is to provide a refugia from which aquatic populations can re-colonize once drought conditions subside. Other important effects of low flow include the purging of drought intolerant invasive species and the germination of riparian vegetation in the low flow channel.

Flow recommendations for all three flow levels were calculated based on pre-development flows in the Brazos basin and followed a basic approach consistent with current scientific literature and recent instream analysis preformed in Texas. Subsistence and Base flows were calculated using the Indicators of Hydrologic Alteration (IHA) software program with subsistence being 10th, dry being the 25th, normal being the 50th and wet being the 75th percentile low flow. High flow pulses and overbank flows were calculated using IHA and USGS PeakFQ programs to estimate 1.5, 4, and 10 year recurrence interval flows.

Figure 10 Ecosystem Flow Recommendations



Brazos River Authority Systems Operation Permit Application

On June 25, 2004, the BRA made an application to the TCEQ for over 1 million acre feet of water (421,000 of which would be firm yield and 660,000 would be available on an interruptible basis). This "Systems Operation Permit" would amend their current requirements to allow for more operational flexibility of existing resources, the collection of, as yet unrealized, wastewater return flows or reuse, and the use of the bed and bank of the Brazos River for the conveyance of water transferred into the basin. This massive permit, probably unprecedented in Texas, would shift much of the responsibility for managing the water resources of the basin from the TCEQ to the BRA. Many of the details as to how the BRA would implement this permit are not included in the permit application, deferring instead to a water management plan to be developed by the BRA after the permit has been issued.

The permit has the potential to significantly alter flows in the Brazos River. These alterations could potentially further degrade the ecological condition of the river. Unfortunately, the lack of specifics in the application makes it impossible to predict, with a high level of certainty, how the permit will impact the ecosystem. Rather than provide a detailed description of the amounts and locations where the requested water will be put to beneficial use, the BRA have opted instead to provide a WAM to the TCEQ. The model that is provided is based on highly unrealistic assumptions and simplifications about how water might be used and moved around the basin; there are three designated locations or control points where their entire diversions, under both their existing permits and so called new application, would be taken. Nonetheless this model is the only significant piece of the application upon which a quantitative assessment might be made and therefore is the focus of specific concerns detailed below.

Water Availability Models

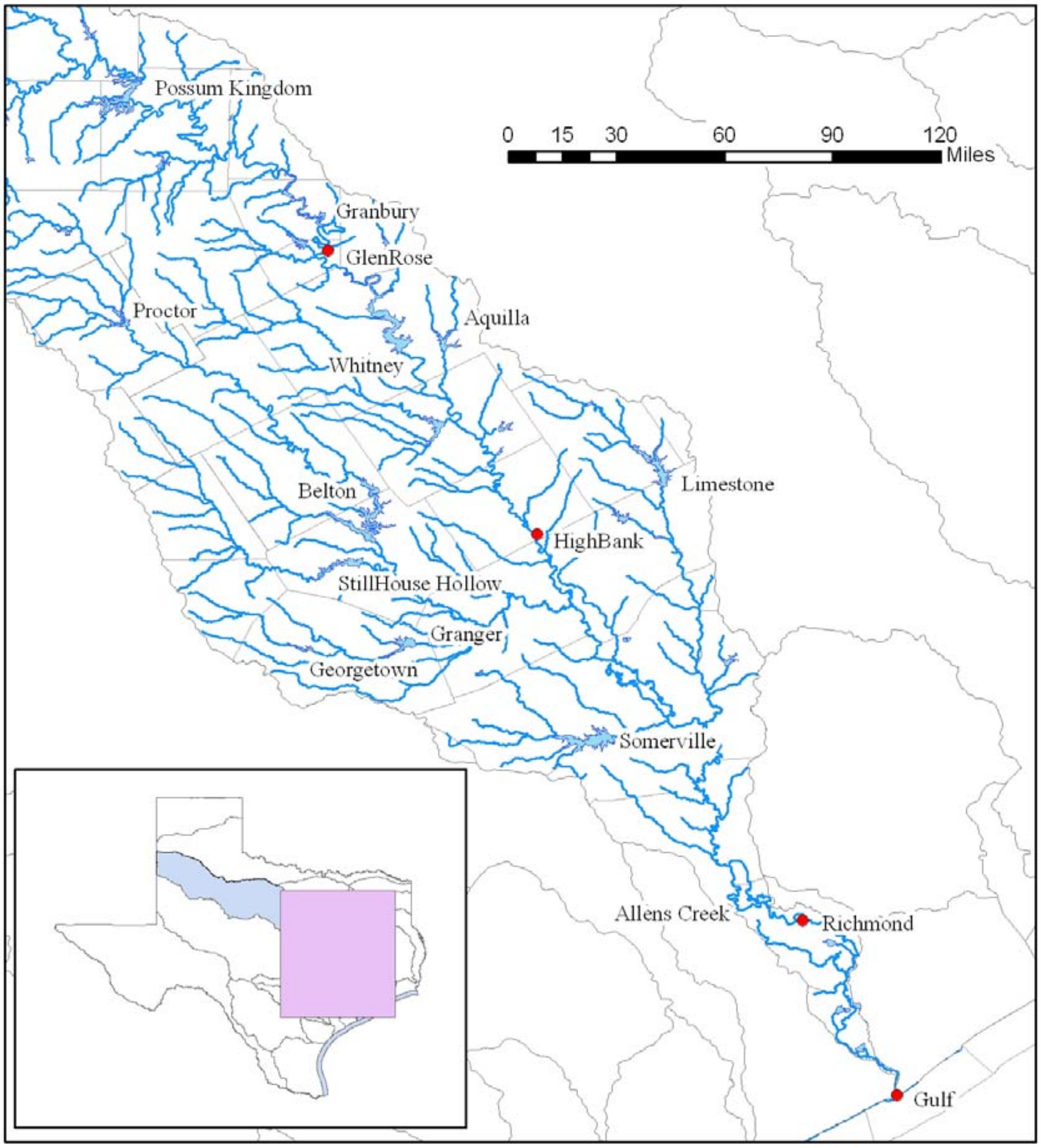
Before detailing concerns about the potential impacts to instream flows by the Systems Operation Permit, it will be instructive to briefly discuss the WAM in general, how it works, the basic assumptions, and how it can be used to evaluate impacts on instream flows. WAMs have been developed for each of the 23 river basins in Texas as part of the 1997 landmark water bill, commonly referred to as Senate Bill 1. Although there are a number of model run options, basically the models superimpose permitted (or projected) water rights on historical hydrology to predict water availability at any location in the river basin. Although the models were developed as part of Senate Bill 1, which is a water planning program, their primary use has been to support TCEQ decisions related to water rights permitting. The TCEQ maintains two versions of the

WAM models. The full authorization simulation (Run3), in which all water rights utilize their maximum authorized amounts and all surface water generated return flows are assumed to be fully reused and not returned to the stream, is used to evaluate applications for perpetual water rights and amendments. The current conditions simulation (Run8), which includes return flows and current diversion rates (based on the maximum use in the last ten years), is used to evaluate applications for term water rights and amendments.

In developing the systems operation permit, BRA created additional code for a WAM specific to this permit. This complex set of algorithms uses outputs from a base run, which is the official TCEQ model (Run3) modified to include projected return flows in 2060, to limit diversions for BRA projects to their current levels. It then adds the new diversions after all other existing permits in the basin are satisfied. In this way the systems operation model minimizes potential impacts on existing permits.

For the systems operation permit application, the BRA listed three potential points where water might be diverted, at Glen Rose, Highbank and the Gulf (which uses the Richmond gage as a reference for instream flows).

Figure 11 Systems Operation Reservoirs and Control Points



In order to evaluate diversions at three potential locations with options for firm and interruptible at each, 6 model runs are required.

1. Glen Rose – Firm
2. Glen Rose – Interruptible
3. Highbank – Firm
4. Highbank – Interruptible
5. Gulf – Firm
6. Gulf – Interruptible

The application also includes the potential that some water could be permitted as interruptible rather than firm. Firm water diversions are diversions which can be made at their full amount in every year (100% of the permitted amount every year). Interruptible water is the amount of water of which 75% can be diverted in 75% of the years. The TCEQ regulatory guidance document allows for the permitting of water that meets the 75/75 rule when the water is not for municipal purposes or when the municipal users can show an available alternative supply during times of short fall. The analysis in the subsequent pages focuses on Glen Rose firm yield option though it could be applied to any of the alternatives.

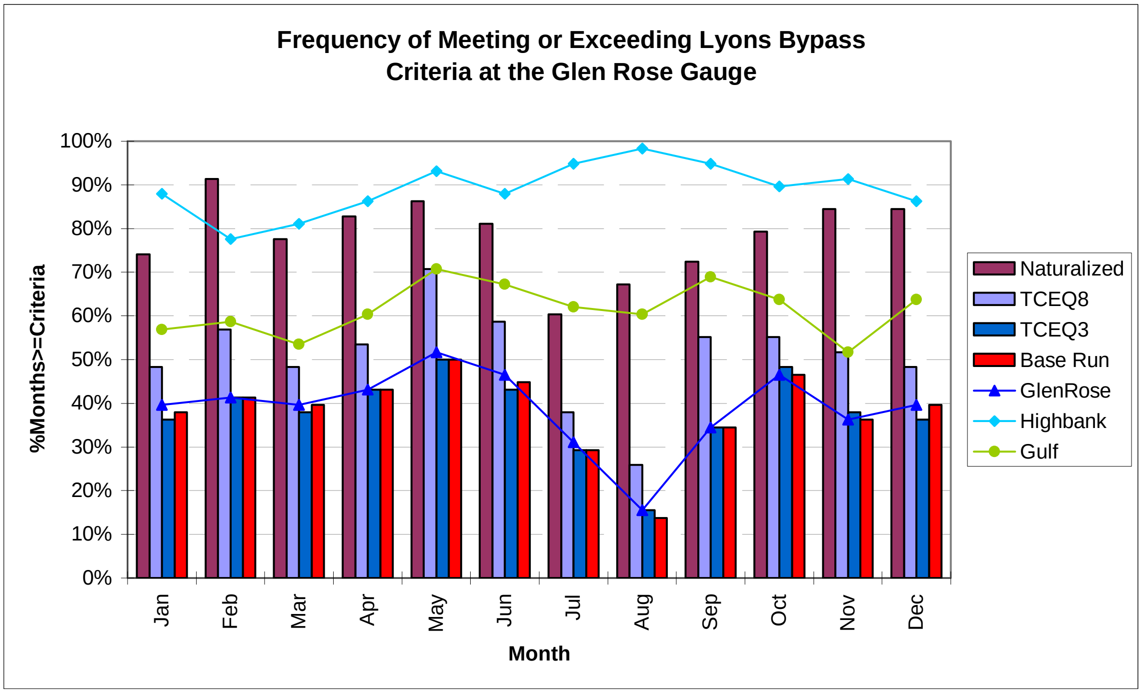
While the WAM models can be useful in understanding how water development might impact riverine ecology, this is not what they were designed for, and as a consequence, ecological conclusions based on WAM results should be viewed as preliminary rather than definitive. The major difficulty in using them to evaluate instream flows is that they operate on a monthly time step. Because of the variability of flows within a month, monthly flows are not useful for environmental or recreational flow needs analysis. Therefore outputs from the WAMs must first be converted to daily flows. The simplest and most straightforward way to accomplish this is to use historical gage flow patterns to distribute monthly flow to a daily time step. This approach assumes that while the daily magnitude of flows may change, the within month pattern will remain the same. This implies that all of the current uses, most notably hydropower releases from Possum Kingdom, will remain as they are and any additional water will simply be added on top of the current pattern. Once this is done the WAM outputs can be used to compare flows under natural, existing and proposed operations.

Permit Application Assumptions Related to Environmental Flows

The environmental analysis in the current application is based primarily on demonstrating that the project will not result in a decrease in the frequency of meeting the Lyon’s flow targets. Even if the Lyon’s targets were a good representation of the flow regime necessary to maintain the ecology of the Brazos River, some of the assumptions implicit in the BRA permit application need to be considered. The first assumption is that as long as the frequency of meeting these targets is not decreased as compared to the base run, then the river will be healthy. The base run proposed by the BRA represents the future conditions of the river without the project. This is not an acceptable approach for two important reasons. First, because it disregards the currently degraded conditions of the Brazos River, the loss of native species and general disruption of the aquatic community as a result of the instream impoundments; maintenance of the status quo is not a sufficient goal. Rather the proposed Systems Operation Permit should have as its aim to begin to restore some of the ecological structure and function that the river has lost over the last 40 years.

Second, because base run against which the impacts of the various project alternatives are compared is an extreme future scenario, one unlikely to be realized without additional degradation to the riverine system. Figure 12 is a modification of the analysis provided by BRA in their application. It shows the percent of time that the Lyons flow targets are met under different model runs. The base run used in the permit application is essentially the TCEQ WAM Run 3 modified to include return flows. The TCEQ WAM Run 3 assumes the full use of all existing water rights. Given that many of the current water rights have never been fully exercised it is clear, as can be seen in Figure 12 that the base run includes significant flow alterations as compared to the current existing conditions, TCEQ WAM Run8. The target flows would be met 10-15% less often just by full utilization of existing permits. This decline would occur in a system which has already been significantly altered as seen by the 20-30 percent drop from natural conditions.

Figure 12 Frequency of Meeting or Exceeding Lyons Bypass Criteria at Glen Rose



Surplus Water Available for Instream Flows

The systems operation permit is intended to meet long term demands up to at least 2050. Table 2 indicates that there will be a significant surplus of available water until 2030. Beyond that time the surplus decreases though a large part of that decrease is related to increased demands at Lake Allen Henry which is not a part of the systems operation. Some of the surplus water not currently needed for out of stream uses could be used to provide the base and high flows to protect the biological integrity of the Brazos.

Table 2 Summary of Water Demands from Brazos River Authority Sources from the 2002 State Water Plan

	2000	2010	2020	2030	2040	2050
Total Demand	587,903	637,359	681,015	735,593	832,711	881,213
Existing Supply	696,901	696,901	696,901	696,901	696,901	696,901
Surplus/Deficit	108,998	59,542	15,886	-38,692	-135,810	-184,312
Systems Operation Supply	910,000	910,000	910,000	910,000	910,000	910,000
Surplus/Deficit	322,097	272,641	228,985	174,407	77,289	28,787

As modeled by the BRA, Glen Rose firm yield alternative would divert a total of 910,000 acre-feet per year. Of this 446,000 would be diverted at Glen Rose and 464,000 would be diverted at the Gulf. The first column (Table 3) shows the monthly diversions in acre-feet that would be made at the Glen Rose location. The out of stream water demands upstream of Glen Rose are only 190,137 in 2020. The total demands downstream of Glen Rose equal 490,878 so some of the water diverted from Glen Rose (26,878 acre-feet per year) would presumably need to be passed downstream. Even accounting for this pass through there appears to be a surplus of 228,985 acre-feet per year at Glen Rose in 2020.

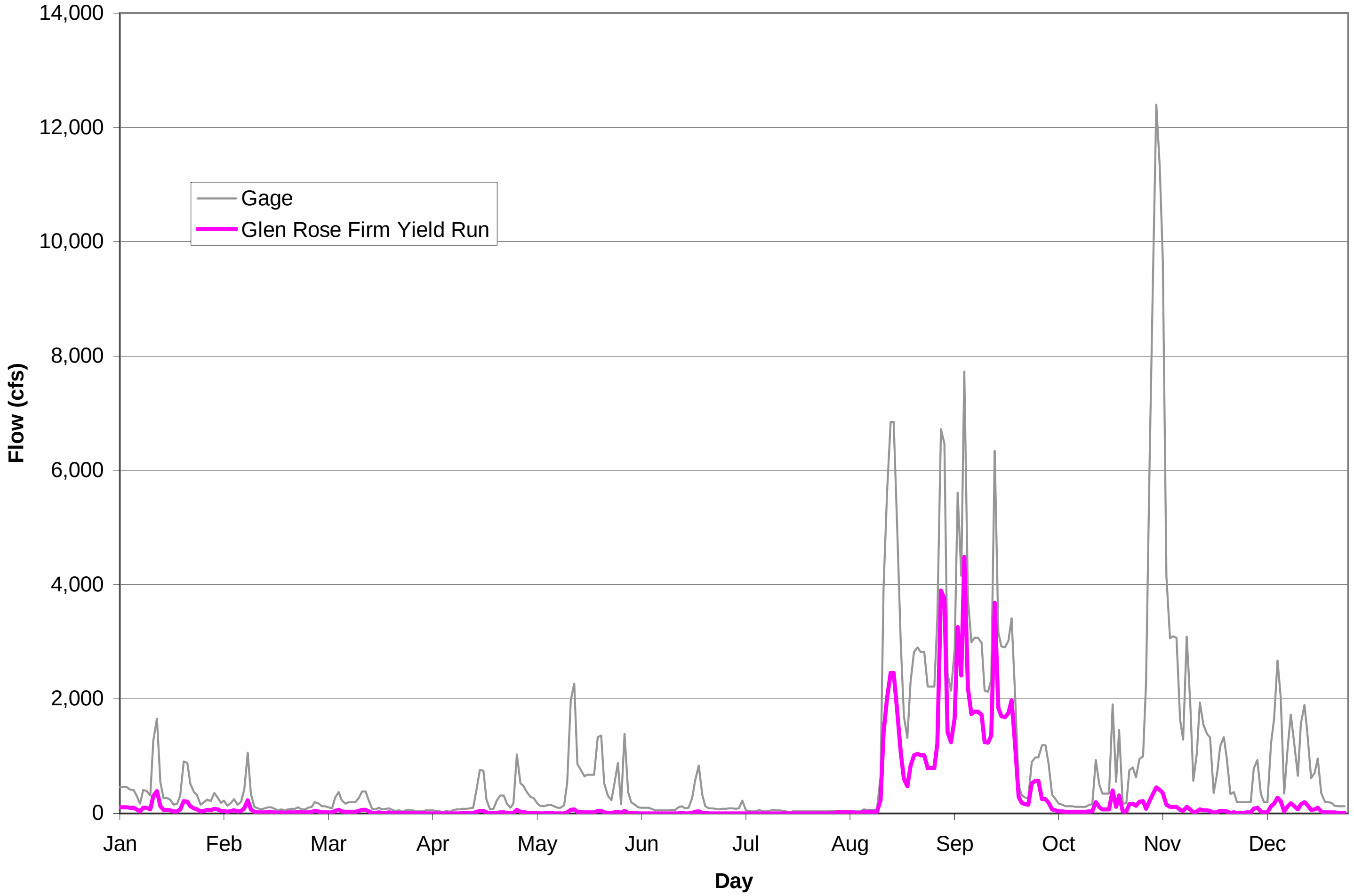
Table 3 Potential Diversions, Demands and Surpluses at the Glen Rose site under the systems operation permit in 2020

	Diversion	2020 Demands	Surplus
Jan	29,495	12,574	15,143
Feb	28,601	12,193	14,684
Mar	31,729	13,527	16,291
Apr	34,411	14,670	17,667
May	41,114	17,528	21,109
Jun	44,689	19,052	22,944
Jul	51,393	21,910	26,386
Aug	46,477	19,814	23,862
Sep	41,114	17,528	21,109
Oct	35,305	15,051	18,126
Nov	31,283	13,336	16,061
Dec	30,389	12,955	15,602
Totals	446,000	190,137	228,985
Total Demand	681,015		
Downstream Demand	490,878		
Gulf Diversion	464,000		
Pass from Upstream	26,878		

Implementation of Instream Flow Recommendations

The surplus water could be used to provide for base flows and occasional pulsed releases to components of the flow regime critical to restoring and maintaining ecosystem health. Using 1972, a rather normal water year in the Brazos, an example illustrated in the following figures demonstrates one option for how this might be achieved. Figure 13 shows gage flows that actually occurred and modeled daily flows with the systems operation permit.

Figure 13 Daily flows at Glen Rose with (Glen Rose Firm Yield Run) and without (Gage) systems operation permit



Notable are the loss of small pulses in the winter and summer and the high pulses in the late fall. The September mid-level pulse appears to be less dramatically impacted.

At the lower flows the impact is even more dramatic (Figure 14). Where observed summer base flows were around 100 cfs in 1972 with significant periods of much higher flow, the Glen Rose Firm yield alternative would result in a flow regime that never reaches 100 cfs and would rarely be higher than 50 cfs.

Figure 14 Daily flows at Glen Rose with (Glen Rose Firm Yield Run) and without (Gage) systems operation permit (only displaying lower flows)

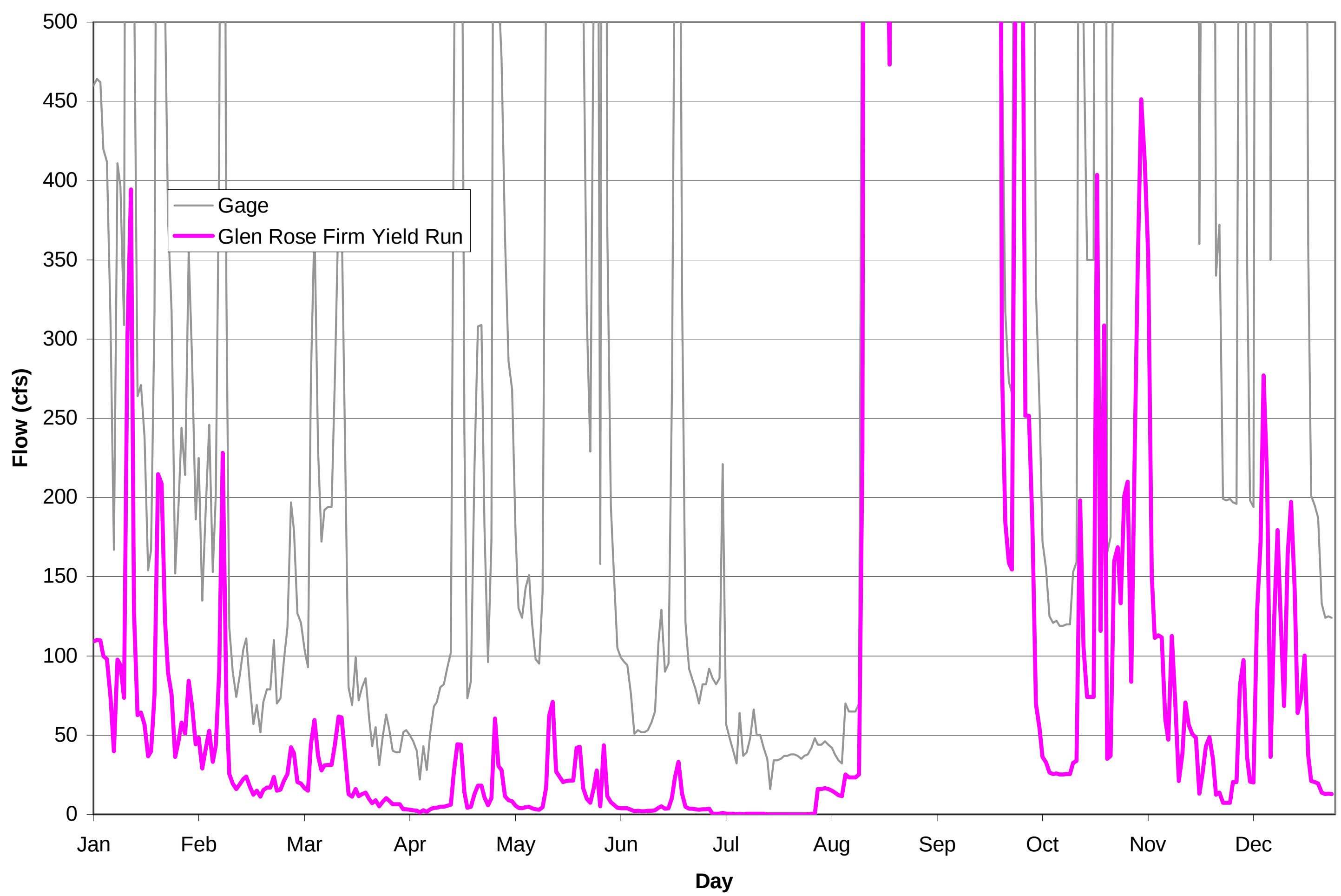


Figure 15 and Figure 16 repeat the information from above but include supplemental flows to meet the targets recommended based on the natural flow regime.

In this example these supplemental flows require about 60,000 acre-feet per year. Obviously, these are overly simplistic examples which would require a far more detailed study to address operational issues including lake level fluctuations and triggers to define whether the current period is experiencing wet, normal or dry conditions. The important point to be made with this example is that reasonable instream flow protection could be maintained with less than a third of the available surplus water forecasted for 2020.

Figure 15 Daily flows at Glen Rose in 1972 with and without the systems operation permit plus 174,407 acre-feet supplemental flow instream needs

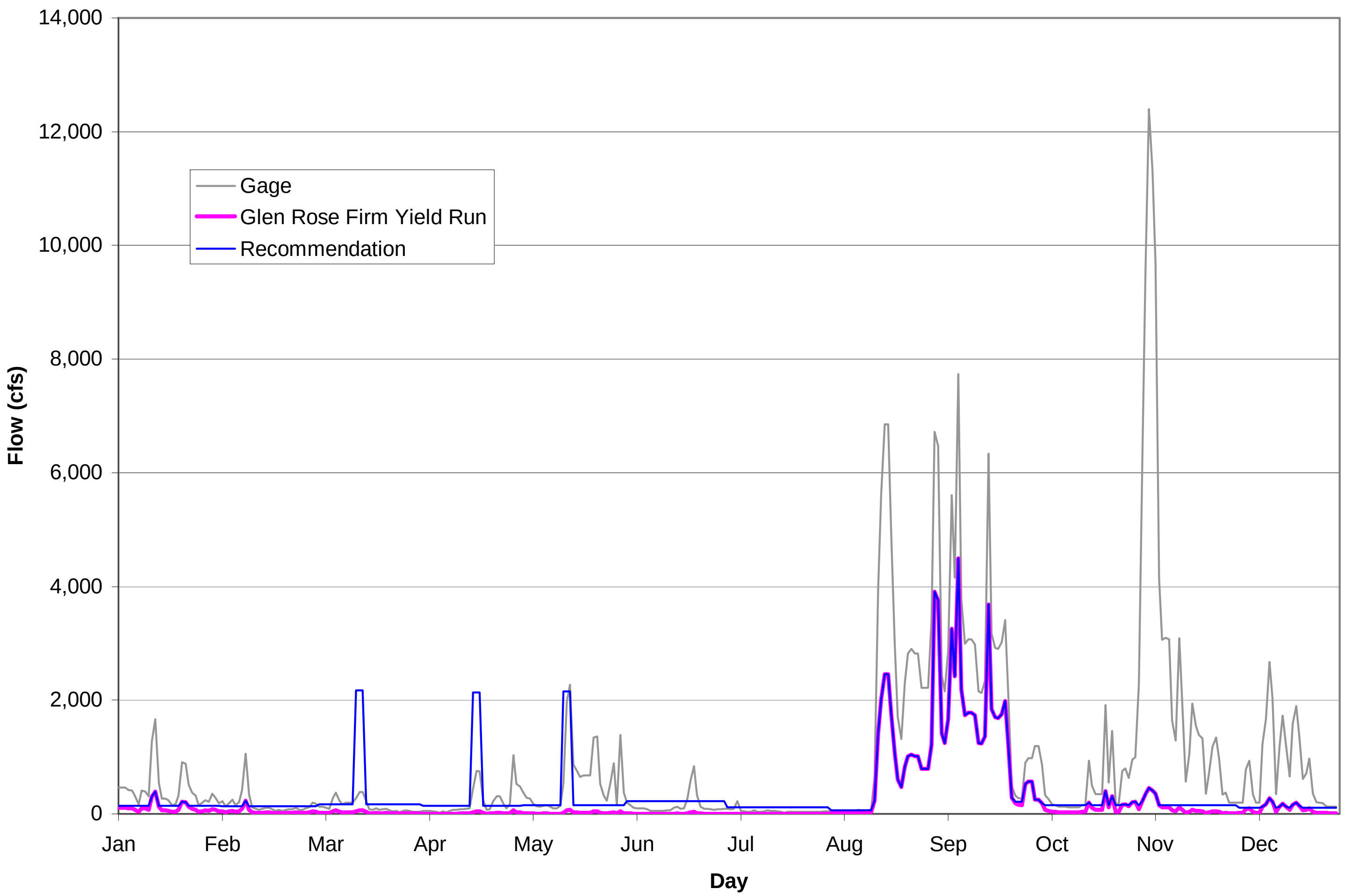
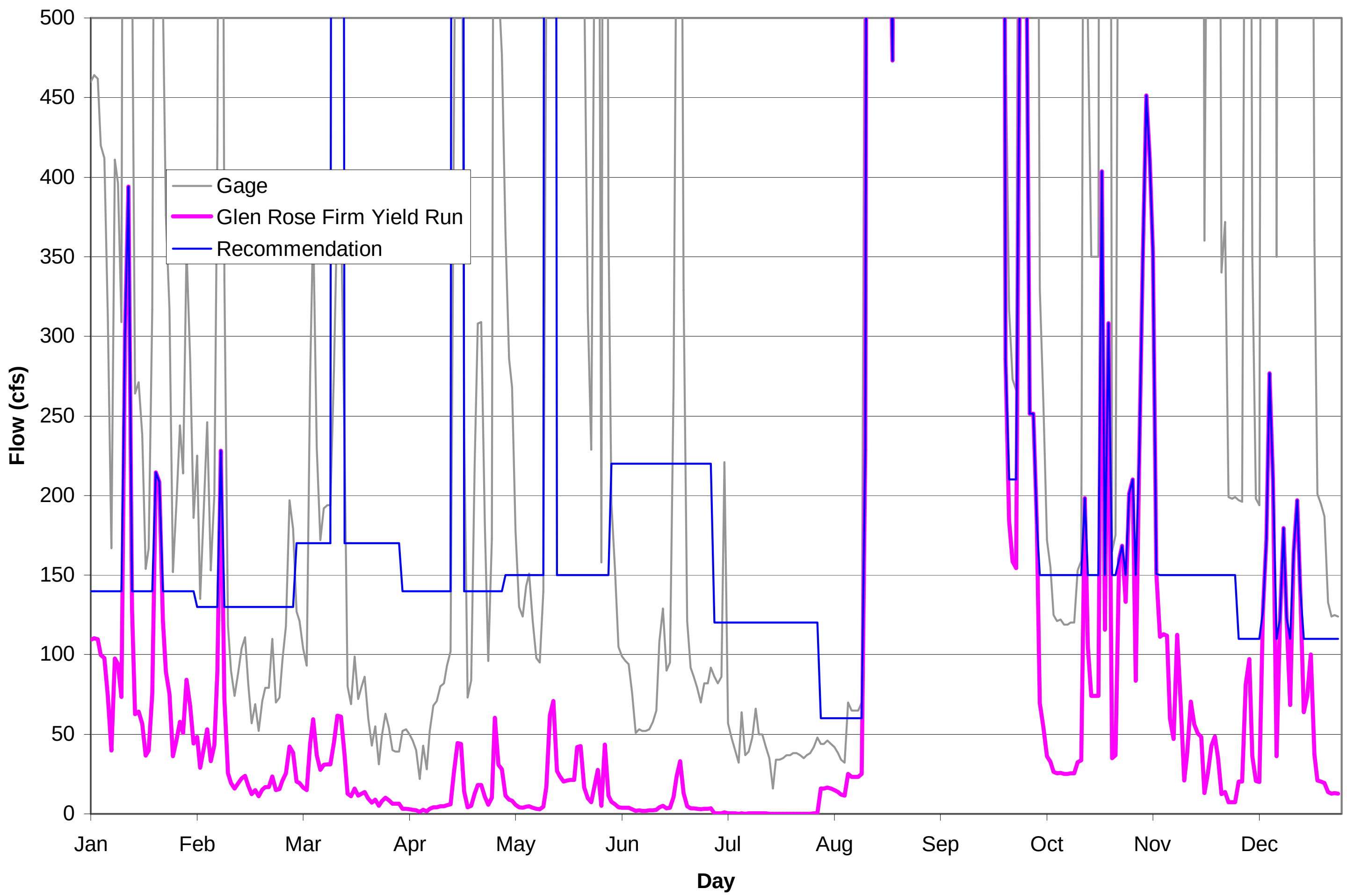


Figure 16 Daily flows at Glen Rose in 1972 with and without the systems operation permit plus 174,407 acre-feet supplemental flow instream needs (only displaying lower flows)



Conclusions

The Brazos River has been significantly altered from its natural condition and the BRA's proposed application for a systems operation permit has the potential to cause further environmental degradation. The sponsors of this project propose addressing the environmental needs of the river in a future water management plan, but after they have the permit to control the remaining water in the basin, there will be little incentive for them to address these environmental needs. The BRA is currently involved in developing an instream flow study; however this study is configured on a now outdated set of assumptions and needs to be redesigned to address the ecological needs of the area that will be impacted by the proposed permit. Since the systems operation produces supplies in excess of human demands, the BRA has an opportunity to demonstrate a proactive commitment to managing the resources in an environmentally responsible manner using the surplus of water that will be available in the foreseeable future. This will also allow for experiments with adaptive management to determine which flow prescriptions are most effective in maintaining and restoring the riverine ecosystem.

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